Memorandum

To: *City of Westminster; Julie Koehler, P.E. Utilities Engineering Manager*

From: *CDM Smith; Tim Rynders, P.E. Project Manager*

Date: *March 15, 2021*

Subject: *DRAFT Technical Memorandum No. 5B – Process Train Selection for Water 2025 Water Treatment Plant*

Executive Summary

This Technical Memorandum (TM 5B) presents the overall approach, evaluation, and recommendations for process train selection for the new water treatment plant (WTP) under the Water 2025 Project.

Process Train Selection Approach

The overall approach for process train selection involved several pre-design investigations and a series of collaborative workshops with the City over the past two years, documented in a series of technical memoranda and study reports. **Appendix A** presents a summary of the key investigations, and implications for the evaluation of treatment process trains for the new WTP.

Water Treatment Design Flows

Design flows for Phase 1 (30 mgd net capacity) and Phase 2 (60 mgd net capacity) of the Water 2025 Project were established for conventional and advanced treatment process train alternatives. These included minimum, average and maximum design flows for the plant and individual unit processes, and the minimum number of process trains in operation to meet these design flows.

Evaluation of Process Train Alternatives

The following process train alternatives were evaluated in this TM:

- **Alternative A – Conventional Process Train**, including conventional pretreatment processes (rapid mixing, flocculation, and high-rate sedimentation), filtration, chlorine for primary disinfection and chloramines for secondary disinfection; and

- **Alternative B – Advanced Process Train**, including conventional pretreatment processes, intermediate ozonation for primary disinfection, biological filtration and chloramines for secondary disinfection. Two sub alternatives consider anthracite and sand filter media (B-1) and granular activated carbon (GAC) and sand filter media (B-2).

The scoring results indicate that Alt B-1 scored highest for three out of the five evaluation criteria, including water quality, regulatory compliance, and environmental sustainability. While Alt A has the lowest capital and operating cost, the inclusion of ozone in the plant process train resulted in less than a 10% project cost addition and the annual operating cost for the ozone system was estimated at $24,000 due to the low required applied ozone dose.

Recommended Process Train

In summary, Alternative B-1-Advanced Process Train with ozone-biofiltration and anthracite and sand filter media is recommended for best value implementation under the Water 2025 Project. It offers the following compelling benefits at a moderate increase in capital cost:

- **Balancing cost and superior water quality performance**: Advanced ozone-biofiltration treatment provides superior water quality performance over conventional treatment, while carrying a slightly lower cost than an advanced treatment train including GAC filter media.
- **Increased resiliency to climate change**: Climate change is resulting in an increased frequency and magnitude of events such as forest fires, floods, and extended droughts. These events can have significant long-term negative impacts on raw water quality. The inclusion of the ozone-biofiltration process in the process provides a robust, best-in-class, resilient multi-barrier treatment approach which will allow Westminster to adapt to variable and challenging raw water quality.
- **Improved constructability and process flow**: Installing ozone in Phase 2, as proposed under the conventional approach (Alt A), results in additional layout costs and increased hydraulic challenges when adding an intermediate process into an existing plant. Installation of ozone with Phase 1 eliminates future layout concerns and simplifies the construction of the current facility.

Next Steps

The next significant milestone upcoming for the Water 2025 project are spring Process Workshops and the Basis of Design report scheduled for July 2021. The information and recommendations presented in this TM will serve as the basis of the Process Workshops and the final design criteria to be included in the Basis of Design report.

Purpose

The City of Westminster (City) is implementing the Water 2025 program, which involves the planned, phased replacement of the aging Semper Water Treatment Plant (WTP) with a new 30 million gallons per day (mgd) WTP (expandable to 60 mgd). To mitigate aging equipment and facilities at Semper, the new WTP is required to be online by end of year 2025. All City water treatment facilities, including the new WTP, will continue to use Standley Lake and Standley Lake supply canals and pipelines as the source water.

The purpose of this Technical Memorandum (TM) is to provide a summary of the process train selection approach, present basic design criteria of the two process train design alternatives that were considered and pilot-tested, and present the recommended process train and conceptual layouts for the new WTP.

Process Train Selection Approach

The overall approach for selecting the most appropriate treatment process train for the new WTP involved several pre-design investigations and a series of collaborative workshops with the City over the past two years. The pre-design investigations included:

- Establish benchmark water quality criteria for normal, challenging, and catastrophic source water quality conditions in Standley Lake, based on historical trends and anticipated future extreme weather events (floods, wildfires, etc.) in the watershed.
- Establish finished water quality and treatment performance goals for the Water 2025 project for current and anticipated future regulatory compliance and improved public health protection.
- Identify screening criteria for process train selection that reflect the City's priorities, such as water quality, operational flexibility and resiliency, ease of operation, sustainability, economics, footprint, hydraulics, and regulatory compliance.
- Perform preliminary screening of candidate water treatment technologies for pilot plant process selection and the desk-top study assessment of unit processes for the new WTP. This assessment led to identification of a *conventional* process train, similar to the Semper WTP with improved pretreatment processes, and an *advanced* process train with ozone and biofiltration treatment processes.
- Perform bench-scale testing, pilot plant testing, and an assessment of historical treatment performance at the Semper WTP to support selection and design criteria development for conventional and advanced treatment process trains for the new WTP, including chemical systems and physical treatment processes.
- Develop conceptual facility layouts, preliminary site plans, and planning-level cost estimates for conventional and advanced treatment process trains for construction of the new WTP on a greenfield site recently selected by the City.
- Select the most appropriate process train for implementation based on the results of these preceding investigations and the Process Train Selection Workshop held with the city on December 15, 2020.

Previous Investigations and Related Documents

The pre-design investigations for the Water 2025 Project are documented in the following technical memoranda and study reports. **Appendix A** presents a summary of the key investigations, and implications for the evaluation of treatment process trains for the new WTP.

- **TM 1 Regulations, Source Water Quality and Finished Water Quality Goals**, October 2019: Presented a regulatory overview, assessment of source water quality conditions, and finished water quality goals which established utility-based and regulatory-based water quality and treatment performance goals for normal, challenging, and catastrophic source water quality conditions.

- **TM 2 Preliminary Regulatory Analysis,** January 2020: Review of environmental resource considerations and preliminary regulatory analysis.

- **TM 3 Bench-Scale Test Results,** January 2020: Findings from the treatability bench-scale study, completed by the University of Colorado, which were also included as **Appendix A** in the desktop study report. The study included bench-scale testing of alternative coagulants and preoxidants for treating raw water samples from the Standley Lake Supply in June, August, and December 2019, and a "first-flush" event on the Farmers Highline Canal in April 2019.

- **Desktop Study Report**, June 2020: Summary of bench-scale and conceptual design work, which included the screening of candidate water treatment technologies, selection of conventional and ozone-biofiltration treatment processes and chemical systems for piloting, and development of preliminary process design criteria, concept layouts, and cost estimates for liquids and solids treatment trains for the new WTP.

- **Pilot Study Report**, March 2021: Summarizes the nine-month pilot plant study to evaluate conventional filtration and ozone-biofiltration processes for treatment of raw water from Standley Lake. The pilot plant equipment was installed at the Northwest WTP and operated by City staff with technical support from CDM Smith from February through November 2020.

Process Train Design Alternatives

Based on the assessment of historical source water quality and treatment performance trends at the Semper WTP, and finished water quality goals established for the Water 2025 program, the following conventional and advanced treatment process trains were selected for the pilot study, as detailed in the desktop report, and are further evaluated in this TM:

- **Alternative A – Conventional Process Train.** This process train includes conventional pretreatment processes (rapid mixing, flocculation, and high-rate sedimentation), filtration, chlorine for primary disinfection, and chloramines for secondary disinfection; and

- **Alternative B – Advanced Process Train**. This process train includes conventional pretreatment processes (rapid mixing, flocculation, and high-rate sedimentation), intermediate ozonation for primary disinfection, biological filtration, and chloramines for secondary disinfection. Two sub alternatives consider anthracite and sand filter media (B-1) and granular activated carbon (GAC) and sand filter media (B-2).

Based on bench-scale results and full-scale operational experience at the Semper WTP, the treatment chemicals for both process trains include: sodium permanganate for preoxidation, ferric chloride for coagulation, lime and sodium hydroxide for pH adjustment and corrosion control, and sodium hypochlorite and ammonium sulfate for chloramination to maintain a distribution system disinfection residual.

WTP Design Flows

Figure 1 presents a general process flow balance schematic with anticipated maximum design flows for the advanced ozone-biofiltration process train and associated unit processes. The process schematic for the conventional process train is similar, except without the intermediate ozone process. To produce the required Phase 1 demand flow of 30 mgd, upstream processes are rated for progressively higher flows to account for water demands from auxiliary processes such as sedimentation basin sludge wastage, filter backwashing, and filter-to-waste. The following residual volume assumptions for the Phase 1 plant design flows are based on CDM Smith experience and pilot testing results:

- **Sedimentation basin sludge wastage**: 0.9 mgd (3% of design capacity)
- **Filter backwashing**: 0.9 mgd (3% of design capacity)
- **Filter to waste**: 0.2 mgd (0.7% of design capacity)
- **Total flow to residuals process**: 2.0 mgd (6.7% of design capacity)
- **Flow recovered from residuals process**: 1.6 mgd (5.3% of design capacity, 80% recovery)

Based on the above assumptions, 30.4 mgd must be withdrawn from Standley Lake for the new WTP to produce 30 mgd finished water "net" flow, assuming 1.6 mgd is recycled from the residuals processes. To simplify the sizing of unit processes, a maximum design flow of 32 mgd is assumed for all unit processes up to but not including the high service pump station.

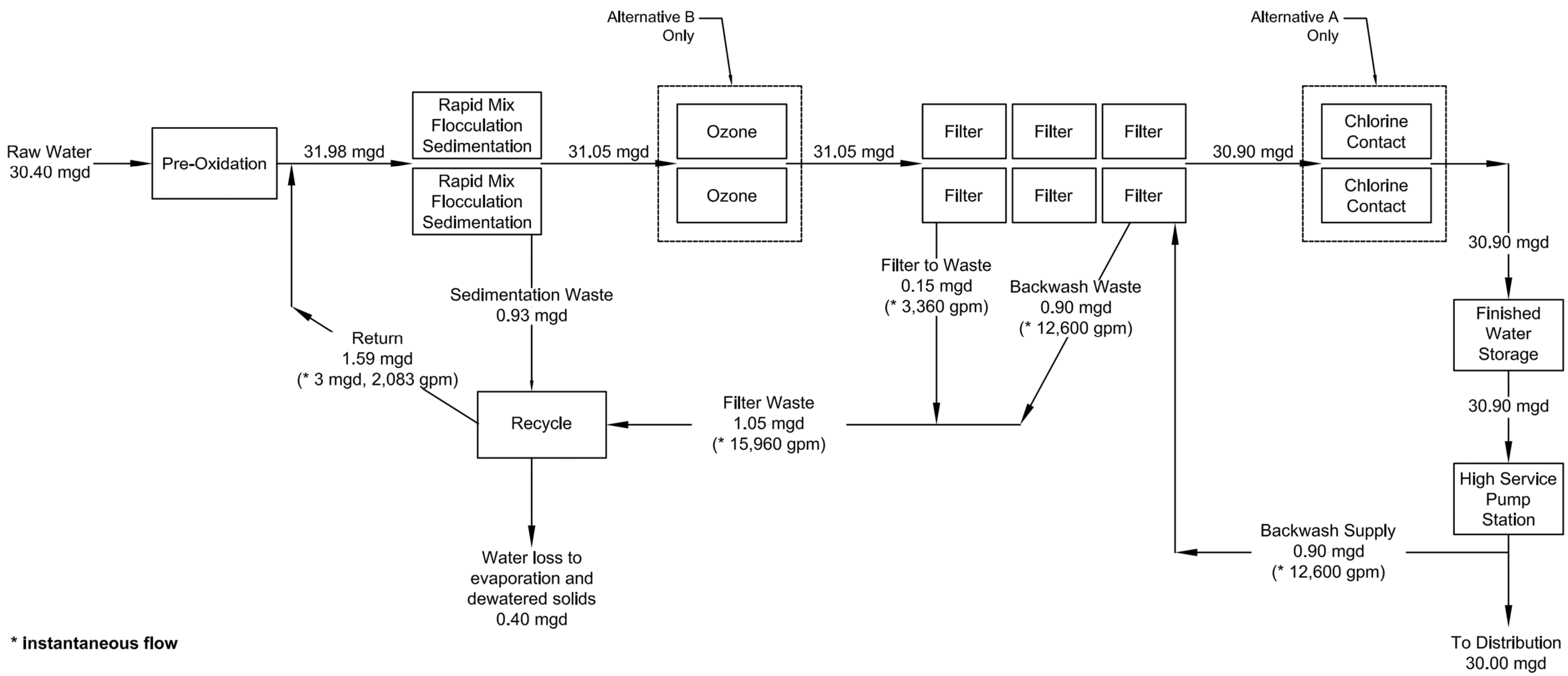


Figure 1: Process Flow Balance Schematic for Advanced Process Train

Table 1 presents the maximum, average, and minimum design flows for Phase 1 and Phase 2 of the project for conventional and advanced treatment process train alternatives. It also includes the unit process design flows and number of process trains in service at each condition. Note that the maximum unit process design flows include the number of filters in service based on the permitted loading rate of 10 gallon per minute per square foot (gpm/ft^2) as well as the loading rate and number of filters in service with one filter per module out of service for backwashing.

Table 1 Phase 1 and Phase 2 Design Flows for Water 2025 WTP

Description	Initial WTP Phase 1			Expanded WTP Phase 2		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Plant Finished Water Flow, mgd	3	10	30	6	20	60
Treatment Module Process Design Flow, mgd	3.2	10.7	32.0	6.4	21.3	64.0
Rapid Mix Basins (Stages 1, 2, and 3)						
Number of Trains in Service	1	2	2	1	2	4
Design Flow per Train, mgd	3.2	5.3	16.0	6.4	10.7	16.0
Flocculation Basins						
Number of Trains in Service	1	2	2	1	2	4
Design Flow per Train, mgd	3.2	5.3	16.0	6.4	10.7	16.0
Sedimentation Basins						
Number of Trains in Service	1	2	2	1	2	4
Design Flow per Train, mgd	3.2	5.3	16.0	6.4	10.7	16.0
Intermediate Ozone Contactors (Alternative B only)						
Number of Trains in Service	1	2	2	1	2	4
Design Flow per Train, mgd	3.2	5.3	16.0	6.4	10.7	16.0
Media Filters						
Number of Filters in Service	2	3	4 / 5	4	6	8 / 10
Design Flow per Filter, mgd	1.6	3.6	8.0 / 6.4	1.6	3.6	8.0 / 6.4
Filter Loading Rate (gpm/ft^2)	2.0	4.4	9.9 / 7.9	2.0	4.4	9.9 / 7.9
Chlorine Contact Basins (Alternative A only)						
Number of Basins in Service	1	2	2	1	2	4
Design Flow per Train, mgd	3.2	5.3	16.0	6.4	10.7	16.0

Description of Process Train Alternatives

Alternative A – Conventional Process Train

Figure 2 presents the process flow schematic for Alternative A – Conventional Process Train with preliminary design criteria for each unit process. It includes three-stage rapid mixing, three-stage flocculation, inclined plate sedimentation, dual media filtration, primary and secondary disinfection, and finished water storage and pumping. The dual media filtration process in an anthracite over sand media configuration.

Pre-oxidation is performed by dosing sodium permanganate at the first-stage rapid mix (static mixer in the raw water pipeline). Ferric chloride coagulant is dosed at the second-stage rapid mix basin (primary dosing point) followed by lime for pH adjustment in the third-stage rapid mix basin. Vertical mixers provide mixing energy for the second and third stage rapid mix. The ferric chloride and lime chemical sequence can be reversed by opening and closing isolation gates between these two mixing chambers if it is desired to increase pH/alkalinity prior to coagulation.

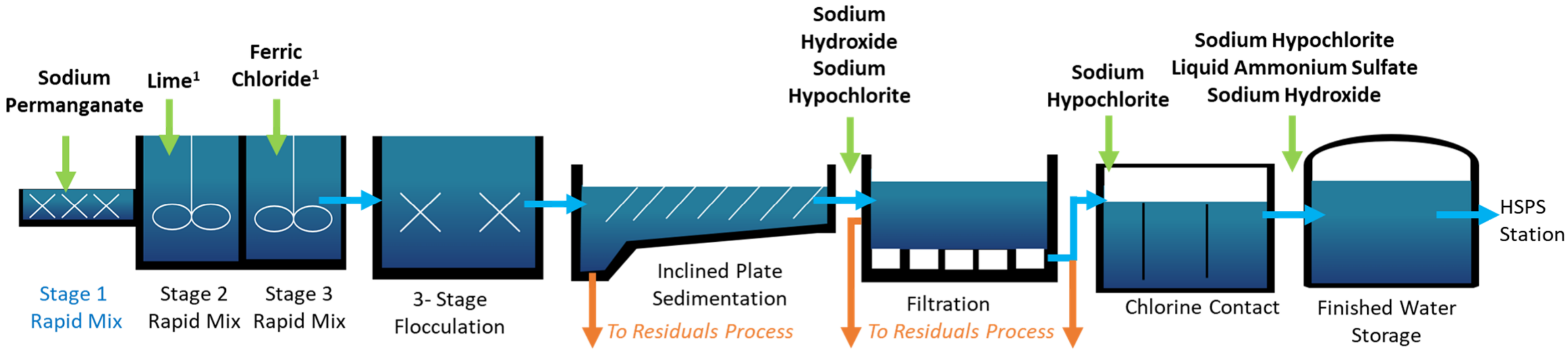
Sodium hypochlorite and sodium hydroxide chemicals are applied to the filter influent for primary disinfection and pH adjustment, respectively. Capability to add a non-ionic polymer for improved particle removal across the filters will also be provided for use during challenging water quality events. Chlorine contact time for primary disinfection is provided in a downstream chlorine contact basin. After filtration, sodium hypochlorite and liquid ammonium sulfate are dosed for secondary disinfection in addition to sodium hydroxide for final pH adjustment.

The preliminary design criteria are largely the same as the Desktop Report, except for parameters that have been added or updated based on findings of the Pilot Study or initial design development; these are highlighted in **Figure 2** in blue. Design alternatives for equipment options for each unit process are discussed in separate TMs. The Basis of Design Report will present final design criteria for the recommended treatment process train.

Table 2 lists the advantages and disadvantages of Alternative A – Conventional Process Train.

Table 2 Conventional Process Train (Alternative A) – Advantages & Disadvantages

Advantages	Disadvantages
▪ Met project goals during pilot testing ▪ No bromate formation potential ▪ Lower capital and operating cost ▪ Two fewer chemical systems compared to Alternative B ▪ Easier O&M with no ozone/calcium thiosulfate (ozone quenching) systems ▪ Lower carbon footprint due to elimination of ozone generator power requirements	▪ Fewer barriers for disinfection of Giardia and viruses compared to advanced treatment train ▪ No reliable barrier for taste and odor events ▪ No barrier for emerging contaminants (CECs) ▪ No barrier for algal toxins ▪ Less TOC and DBP precursor removal compared to advanced treatment train (more biodegradable carbon in distribution system means less biological stability) ▪ Less resilient against climate change and extreme weather events ▪ Larger treatment module footprint due to longer chlorine contact time compared to ozone CT requirements ▪ Complicates the hydraulic layout of the facility as future ozone would have to be installed north of the filters, but operates hydraulically between sedimentation and filters



Type	Static	Mech	Mech
Det. time	1 sec	5 min	0.5 min
Mixer	Westfall	Vertical turbine	Vertical turbine
Vel. Gradient	500-1000 sec^{-1}	300 sec^{-1}	>500 sec^{-1}
Basis	Best Practice	Best Practice	CDPHE

Type	Mech/ Serpentine
Det. time	30 min
Mixer	Vertical Turbine
Vel. Gradient	70,50,30 sec^{-1}
Basis	Best Practice

Type	Inclined-plate
Effective Plate Area Hydraulic Loading Rate	0.4-0.7 gpm/ft^2
Sludge Collection	Flight and Chain, Hoseless Sludge Collector, or Reciprocating Scraper
# of Sludge Collectors	2
Basis	CDPHE

Type	Non-biological
Number	6
Flow	6.2 mgd per filter at 8 gpm/ft^2
Media Type	48” or 60” Anthracite over 12” sand
Hyd. Loading Rate	10 gpm/ft^2 rated, 8 gpm/ft^2 design
Basis	Pilot Plant

Target	0.5-Log Giardia & 2-log Virus
Contactor Baffling	Serpentine
Hyd. Res Time	45 min @1.5 mg/L
Water Depth	18 ft
Basis	EPA CT Table

Solids Process

Type	Backwash Equalization, Gravity Thickening, Dewatering Beds, Mechanical Dewatering
Flow	1.98 mgd (80% Recovered)
Basis	Best Practice

[1]Feed points are reversible
(Blue font indicates added or updated from the Desktop Report)

Figure 2: Alternative A – Conventional Process Train Flow Schematic and Preliminary Design Criteria

Alternative B – Advanced Process Train

Figure 3 presents the process flow schematic for Alternative B – Advanced Process Train, including preliminary design criteria for each unit process. It includes three-stage rapid mixing, three-stage flocculation, inclined plate sedimentation, intermediate ozonation, biologically active dual media filtration, primary and secondary disinfection, and finished water storage and pumping. Two subsets of Alternative B were considered: B-1 which uses an anthracite over sand media configuration in the biological filtration process and B-2 which uses GAC filter media in place of the anthracite.

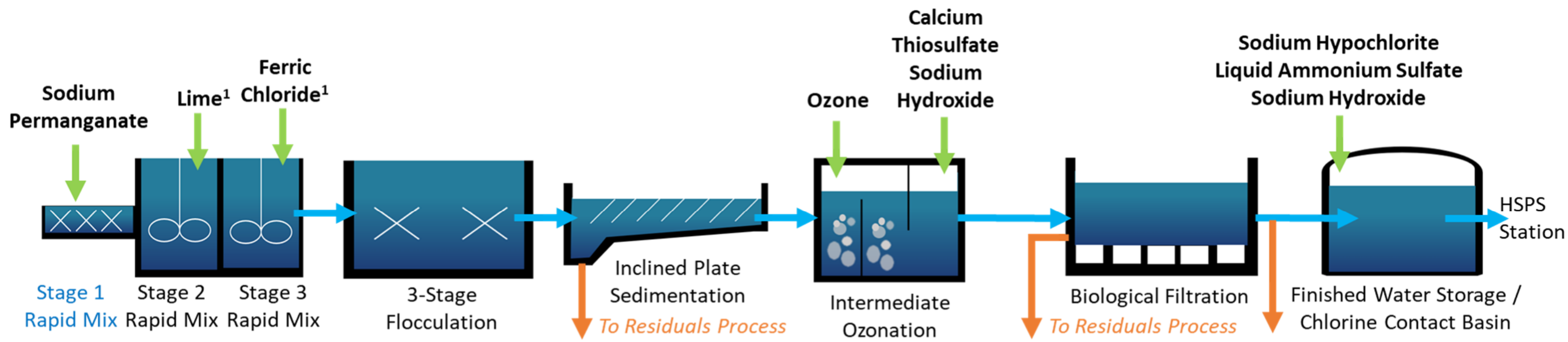
The chemical dosing and mixing arrangement for the three rapid mix stages is identical to Alternative A. An intermediate ozonation process between the sedimentation and filtration processes is used instead of a post-filter chlorine disinfection process for primary disinfection. Ozone is injected at the front end of the intermediate ozone contactor using a sidestream injection dissolution system. Calcium thiosulfate, for ozone residual quenching, sodium hydroxide for pH adjustment, and (if necessary) a polymer for improved particle removal across the filters, are dosed near the outlet end of the ozone contactors. After filtration, sodium hypochlorite and liquid ammonium sulfate are dosed to form chloramines for secondary disinfection in addition to sodium hydroxide for final pH adjustment trim (as needed).

As with Alternative A, the preliminary design criteria are generally the same as the Desktop Report. Additional or updated design criteria, based on findings of the Pilot Study or industry best practice, are highlighted in **Figure 3** in blue. Dedicated unit process TMs discuss equipment alternatives available for each process and the Basis of Design Report will present the final design criteria.

Table 3 lists the advantages and disadvantages of Alternative B – Advanced Process Train for the new WTP.

Table 3 Advanced Process Train (Alternative B) – Advantages & Disadvantages

Advantages	Disadvantages
▪ Met project goals during pilot testing ▪ Additional barriers for disinfection of Giardia and viruses ▪ Barrier for taste and odor (T&O) events ▪ Barrier for contaminants of emerging concern (CEC) ▪ Barrier for algal toxins ▪ Improved TOC and DBP precursor removal ▪ Incorporates ozone between sedimentation and filters to eliminate need for post-filter chlorine contact basin ▪ Smaller footprint for advanced treatment modules compared conventional treatment module due to elimination of chlorine contact basin	▪ Potential bromate formation ▪ Higher capital and operating cost ▪ Two additional chemical systems compared to Alternative A ▪ Higher carbon footprint due to higher power consumption requirements for the ozone generation system



	Stage 1 Rapid Mix	Stage 2 Rapid Mix	Stage 3 Rapid Mix
Type	Static	Mech	Mech
Det. time	1 sec	5 min	0.5 min
Mixer	Westfall	Vertical turbine	Vertical turbine
Vel. Gradient	500-1000 sec^{-1}	300 sec^{-1}	>500 sec^{-1}
Basis	Best Practice	Best Practice	CDPHE

	3-Stage Flocculation
Type	Mech/ Serpentine
Det. time	30 min
Mixer	Vertical Turbine
Vel. Gradient	70,50,30 sec^{-1}
Basis	Best Practice

	Inclined Plate Sedimentation
Type	Inclined-plate
Effective Plate Area Hydraulic Loading Rate	0.4-0.7 gpm/ft^2
Sludge Collection	Flight and Chain, Hoseless Sludge Collector, or Reciprocating Scraper
# of Sludge Collectors	2
Basis	CDPHE

	Intermediate Ozonation
Dose	1-2 mg/L
Gas feed	LOX
Generators	2 @ 250 or 500 ppd
Type	Sidestream injection
Contactor Baffling	Serpentine
Hyd. Res. Time	10 min
Basis	CDPHE

	Biological Filtration
Type	Biological
Number	6
Flow	6.2 mgd per filter at 8 gpm/ft^2
Media Type	48"-60" GAC or Anthracite over 12" sand
Hyd. Loading Rate	10 gpm/ft^2 rated, 8 gpm/ft^2 design
EBCT	3.8-4.7 min at 8 gpm/ft^2
Basis	Pilot Plant

	Finished Water Storage / Chlorine Contact Basin
Target	0.5-Log Giardia & 2-log Virus
Contactor Baffling	Serpentine
Hyd. Res Time	45 min @ 1.5 mg/L
Water Depth	18 ft
Basis	EPA CT Table

Solids Process

Type	Backwash Equalization, Gravity Thickening, Dewatering Beds, Mechanical Dewatering
Flow	1.98 mgd (80% Recovered)
Basis	Best Practice

(Blue font indicates added or updated from the Desktop Report) [1]Feed points are reversible

Figure 3: Alternative B – Advanced Process Train Flow Schematic and Preliminary Design Criteria

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Solids Handling Alternatives

Both Alternatives A and B include the same residuals handling process. TM 14 outlines the residuals handling alternatives including estimates of the solids loading and preliminary design criteria. The preliminary residuals process for Phase 1 includes backwash equalization, gravity thickening, mechanical dewatering, dewatering beds, and return flow/decant pumping.

Liquid residuals from the filter backwash and filter-to-waste flow streams are sent to the equalization basin which is drained at a controlled rate to the dewatering beds. Solid residuals from the sedimentation basins are sent to the gravity thickener. Decant from the gravity thickeners and liquid recovered from mechanical dewatering are sent to the dewatering beds and decant/underdrains from the dewatering beds are sent to a decant pump station which returns flow to the head of the plant.

Underflow from the gravity thickeners are pumped to the mechanical dewatering process under normal conditions, but can also be sent to the dewatering beds for shorter durations. Sludge that has been directed to the dewatering beds is stored for drying. Dewatered solids from the dewatering beds and mechanical dewatering processes are expected to be hauled off-site for disposal or beneficial re-use.

Evaluation of Process Train Alternatives

Methodology

The following evaluation criteria and weights were selected at the Treatment Process Selection Workshop to evaluate, rank, and select the preferred process train alternative for the new WTP.

- **Physical considerations** (land use/footprint and hydraulics) – ***10%***
- **Technology** (ease of operation and maintenance (O&M), reliability and redundancy, and system flexibility) – ***30%***
- **Environmental Sustainability** (carbon footprint, residual generation, and Envision criteria) – ***15%***
- **Economics** (capital cost and O&M cost) – ***15%***
- **Water quality and regulatory compliance** (Microbiological, aesthetics, corrosion control, disinfection byproducts, and contaminants of emerging concerns) – ***30%***

Each process train alternative was assigned a score from 1 to 5 (5 being the best score) for each technical criterion listed above. The alternatives were scored based on their relative strengths and weaknesses with respect to meeting the above criteria. The assigned weights for each criterion were applied to these scores and used to calculate a total weighted score for each alternative.

Comparison of Alternatives

Table 4 presents the technical comparison for three process train design alternatives:

- **Alt A**: Conventional treatment process train with chlorine for primary disinfection and anthracite-sand filter media configuration
- **Alt B-1**: Ozone-biofiltration treatment process train with ozone for primary disinfection and anthracite/sand filter media configuration
- **Alt B-2**: Ozone-biological treatment process train with ozone for primary disinfection and GAC/sand filter media configuration.

Table 4 Evaluation of the Treatment Process Train Alternatives

Criteria	ALT A	ALT B-1	ALT B-2
	Conventional Treatment Train	Advanced Ozone-Biofiltration Treatment	Advanced Ozone-Biological Activated Carbon Treatment
Physical Considerations *(Weight = 10%)*	▪ Larger overall treatment module footprint ▪ Large chlorine contact basin (45-min HDT) ▪ HGL profile similar across alternatives (CCB vs. ozone) ▪ Complicated hydraulic flow if ozone is added at a later date (Phase 2)	▪ Smaller overall treatment module footprint ▪ No CCB ▪ Small ozone contact basin (10-min HDT) ▪ HGL profile similar across alternatives (CCB vs. ozone)	▪ Same as Alt B-1
Score	4	5	5
Technology *(Weight = 30%)*	▪ Familiar O&M requirements; process is similar to Semper WTP ▪ Standard control system for chlorine disinfection ▪ Similar O&M requirements for anthracite/sand filters as Alts B-1 and B-2 ▪ Fewer treatment options to meet WQ goals during challenging and catastrophic source WQ conditions	▪ New ozone process will require operator training ▪ Highly automated control system for ozone disinfection ▪ Similar O&M requirements for anthracite/sand filters as Alts A and B-3 ▪ Advanced treatment process (ozone-biological filtration) available to meet WQ goals during challenging and catastrophic source WQ conditions	▪ Same as Alt B-1, except two advanced treatment processes (ozone plus GAC) available to meet WQ goals during challenging and catastrophic source WQ conditions
Score	5	4	4

<table>
<tr><th rowspan="2">Criteria</th><th>ALT A</th><th>ALT B-1</th><th>ALT B-2</th></tr>
<tr><th>Conventional Treatment Train</th><th>Advanced Ozone-Biofiltration Treatment</th><th>Advanced Ozone-Biological Activated Carbon Treatment</th></tr>
<tr><td>Environmental Sustainability
(Weight = 15%)</td><td>▪ Lower carbon footprint (no ozone system or GAC filter media)
▪ More concrete required for larger CCB structure
▪ Least resilient treatment against water quality change due to extreme weather events</td><td>▪ Higher carbon footprint (ozone generated onsite)
▪ Less concrete required for smaller ozone contactor structure
▪ More resilient treatment (ozone) against water quality change due to extreme weather events</td><td>▪ Highest carbon footprint (ozone generated onsite and GAC filter media)
▪ Less concrete required for smaller ozone contactor structure CCB structure
▪ Most resilient treatment (ozone and GAC) against water quality change due to extreme weather events</td></tr>
<tr><td>Score</td><td>4</td><td>5</td><td>4</td></tr>
<tr><td>Economics
(Weight = 15%)</td><td>▪ Lowest capital cost
▪ Lowest operating cost</td><td>▪ 10% higher capital cost
▪ Slightly higher operating cost</td><td>▪ 10% plus higher capital cost (minor increase for GAC cost)
▪ Slightly higher operating cost</td></tr>
<tr><td>Score</td><td>5</td><td>4</td><td>3</td></tr>
<tr><td>Water Quality/ Regulatory Compliance
(Weight = 30%)</td><td>▪ Fewer treatment barriers and lower log inactivation credits for disinfection of Giardia and viruses
▪ No treatment barrier for taste and odor events
▪ No effective treatment barrier for CECs
▪ No effective treatment barrier for algal toxins
▪ Higher filtered water turbidity and shorter filter runs (based on pilot test results)
▪ Lower TOC and DBP precursor removal across the filters resulting in lower biological stability in distribution system</td><td>▪ More treatment barriers (ozone) and higher log inactivation credits for disinfection of Giardia and viruses
▪ Effective treatment barrier (ozone-biofiltration) for taste and odor events
▪ Effective treatment barrier (ozone) for CECs
▪ Effective treatment barrier (ozone) for algal toxins
▪ Lower filtered water turbidity and longer filter runs (based on pilot test results)
▪ Higher TOC and DBP precursor removal across biological filters resulting in higher biological stability in distribution system (ozone-biofiltration process)</td><td>▪ Same as Alt B-1, except:
- Effective treatment barrier (ozone-biofiltration, GAC) for taste and odor events
- Effective treatment barrier (ozone, GAC) for CECs</td></tr>
<tr><td>Score</td><td>3</td><td>5</td><td>5</td></tr>
<tr><td>Total Score</td><td>4.2</td><td>4.6</td><td>4.3</td></tr>
<tr><td>Ranking</td><td>3</td><td>1</td><td>2</td></tr>
</table>

The scoring results indicate that Alt B-1 scored highest for three out of the five criteria. Alt B-1 and Alt B-2 significantly outscored Alt A with respect to water quality and regulatory compliance - the most heavily weighted criterion. While all alternatives will comfortably fit on the plant site, Alt B-1 was scored higher than Alt A due to elimination of the chlorine contact basin and the smaller footprint for the ozone contactor and stacked generation room. Finally, Alt B-1 scored slightly higher for environmental sustainability, which was based on favoring a more resilient process train for responding to future extreme weather events against a larger carbon footprint for the ozone system.

In summary, Alt B-1 is the preferred process train alternative, offering attractive benefits with respect to physical considerations, environmental sustainability, and water quality at a moderate increase in capital cost at approximately 10 percent higher than conventional treatment.

Cost Comparison of Process Train Alternatives

Planning-level construction costs for the conventional and advanced process train alternatives were previously estimated in the Desktop Report (June 2020) using a parametric model; the results are summarized in **Table 5**. This evaluation indicates that including ozonation in Phase 1 results in less than a 10% project cost addition. As discussed in Description of Process Train Alternatives, deferring ozonation to a future phase would result in additional piping and concrete structural work in Phase 1 to accommodate a future ozone retrofit, increasing construction costs for the conventional process train alternative. Detailed refinements to this cost estimate will be included in the forthcoming Basis of Design Report that will account for decisions taken on the following project components:

1. Specific cost estimates for the selected process components and residual handling alternatives that will be determined at the preliminary design workshops.
2. Anticipated construction cost savings compared to some benchmark facilities due to the pilot facility supporting the variance request for a 10 gpm/ft^2 filtration rate (5 gpm/ft^2 is the maximum filtration rate without pilot data/variance approval from CDPHE).
3. Potential deferment of buildout support facilities to Phase 2, such as some administrative and water quality buildings.
4. Seeking primary disinfection credit with ozone from CDPHE could decrease the required chlorine contact time/volume under normal operation

Table 5 Planning level Construction Cost Estimates for WTP Process Train Alternatives

Description	Ozone-Biofiltration WTP	Conventional WTP
Estimated Construction Planning Cost -15% to +20% Range (assumed 4% annual escalation	\$155.2 - \$219.2 (9 to 9.5% increase)	\$141.8 - \$200.2
Estimated Construction Planning Cost -15% to +20% Range (assumes 3% annual escalation)	\$147.9 - \$208.8 (9.5% increase)	\$135.1 - \$190.8

Ozone Equipment Cost Estimate

The use of industry developed installed equipment costs are available for ozonation facilities. The benefit of these cost curves is that the applied ozone dose and system capacity is used and therefore may be more specific cost estimates than the previously developed parametric models. The ozone demand decay bench test results (**TM 3 – Appendix C of the Desktop Report**) and pilot test results (**TM 5**) were used to establish a maximum ozone of 2 mg/L at 32 mgd. This results in a 1,000 pound per day (ppd) ozone generation system, assuming two ozone generators (1 duty, 1 standby), as shown below in **Figure 4**. The cost curves indicate \$6.5M in installed capacity capital costs (in 2017 dollars). Escalating this amount to 2024 and applying 25% contingency to allow for site specific design conditions and preferences results in an estimated ozone system cost of \$9.9M. This cost is approximately \$3.15M lower than the current planning level estimate included in the desktop report.

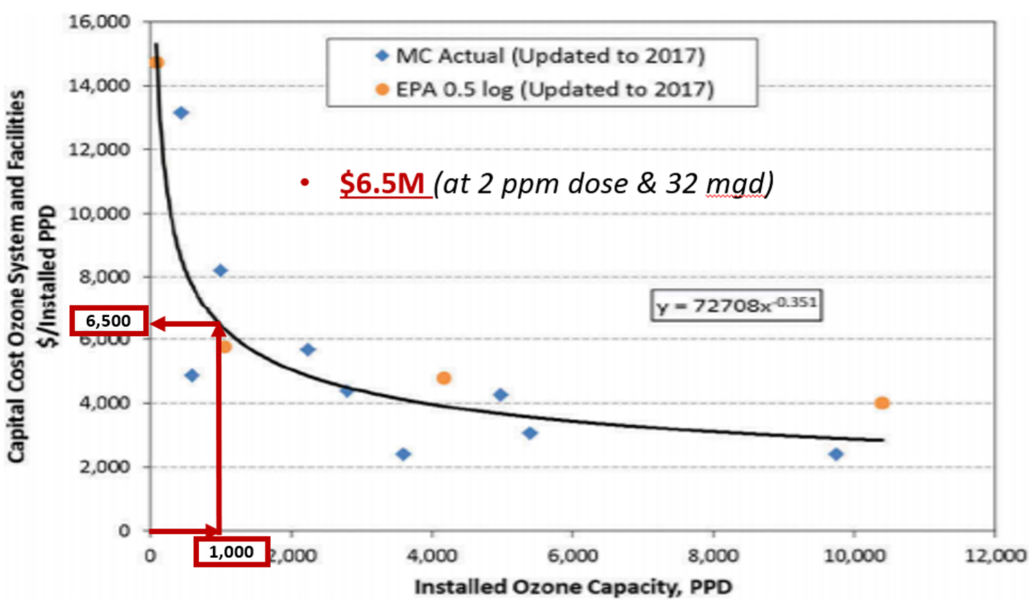

Figure 4: International Ozone Association Cost Curve for Municipal Ozone Projects, OS&E 2018, 2017 dollars

Ozone Equipment O&M Cost Estimate

Table 6 presents the preliminary operating cost for the ozone system at an average flow of 10 mgd, average ozone dose of 1.0 mg/L, liquid oxygen unit cost of $0.31 per 100 cubic feet, and power unit cost of 10 cents per kWh. The annual operating cost is estimated to be approximately $24,000/year. This amounts to less than 1 percent of the current annual operating cost for the Semper WTP.

Table 6: Preliminary Operational Cost for Ozone System

Parameter	Unit	Value
Ozone Operating Condition		
Average Design Flow	mgd	10.0
Ozone Dose	mg/L	1.0
Ozone Concentration	%	10.0
Ozone Production Rate	ppd	83.4
Oxygen Supply Gas Flow Rate	scfm	6.9
Ozone Specific Energy Consumption	kWh/lb	4.0
Power Cost		
Unit Power Cost	$/kWh	$0.10
Daily Power Cost	$	$33
Annual Power Cost	$	$12,176
Liquid Oxygen (LOX) Cost		
Unit LOX Cost	$/100 ft^3	$0.31
Daily LOX Cost	$	$31
Annual LOX Cost	$	$11,301
Total Operating Cost		
Daily Operating Cost	$/day	$64
Annual Operating Cost	$/year	$24,000
Unit Mass Cost	$/lb Ozone	$0.77

Recommended Treatment Process Train

Based on the evaluation of process train design alternatives, results of pilot testing and desktop report assessments, and input from the City at the Process Train Selection Workshop, CDM Smith recommends proceeding with Alternative B-1 - an advanced ozone-biofiltration process train with anthracite/sand filter media configuration.

Figure 5 presents a conceptual layout of the advanced treatment module for the new WTP, including upper and lower level plan views. This layout was used in developing the preliminary site plan for the new WTP, presented in TM No. 20. A general description of the treatment module and key operational features is provided below.

Conceptual Layout for Advanced Treatment Module

As shown in **Figure 5**, the advanced treatment module is laid out in two parallel trains. Each train can be hydraulically isolated by means of gates and valves located between each unit process. Each train has a peak rated capacity of 16 mgd (32 mgd total) which produces a net 30 mgd of finished water flow after subtracting residual process and internal recycle flows. The pretreatment basins and intermediate ozone process are rated at 16 mgd for each train. The permitted filter loading rate of 10 gpm/ft^2 allows each filter bank (3 filters) to operate at flows up to 16 mgd with one filter out of service for backwash. In addition, the maximum treatment capacity of 32 mgd can be produced with only four filters in service. This design flow scenario will allow one filter to be down for maintenance and another in backwash. A complete listing of WTP and unit process design flows are presented in **Table 1**.

Lower Level Description

The lower level of the treatment module is located at grade elevation. A utility corridor runs the entire eastern flank of the treatment block. This corridor connects the Chemical Building with three cross galleries in the main treatment building: rapid mix, intermediate ozone, and filter maintenance galleries. Waste backwash water piping for the Train B filters and overflow piping is routed underneath this gallery and the utility corridor. Chemical piping will be routed the length of the utility corridor and delivered from the Chemical Building to various chemical application points in the treatment process. The Phase 2 facility will directly connect on the east side of this utility corridor by means of transfer pipelines to be constructed between common process channels, as shown on the preliminary site plan (see TM No. 20).

At the south (influent) end of the treatment block, the rapid mix gallery houses raw water piping, flow meters, and chemical application points. A pipe connection between the raw water and overflow pipe header will allow for raw water flushing and flexibility during plant commissioning. The intermediate gallery between sedimentation and ozone houses the sidestream injection pumps and venturi injectors for the ozone dissolution system, ozone residual sample stations, ozone contactor access manways, and settled water piping and associated flow metering. This gallery connects to the filter pipe gallery through a central corridor between the ozone contacting basins.

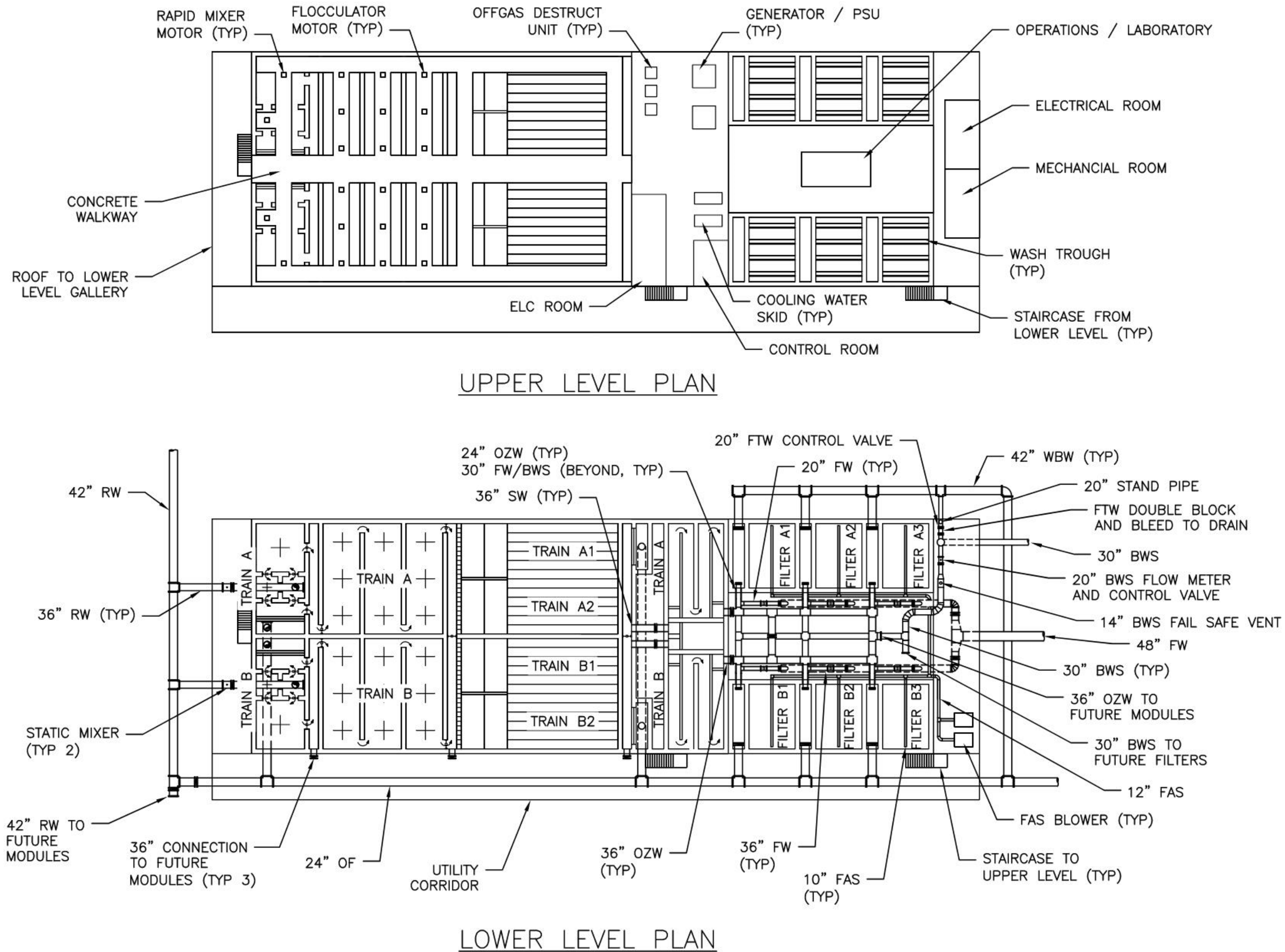

Figure 6: Conceptual Layout of the Advanced Ozone-Biofiltration Process Train Module

The filter pipe gallery houses the two ozonated water pipe headers, individual filtered water piping for each of the six filters, two combined filtered water pipe headers located below the gallery floor, and backwash supply piping. The filter pipe gallery connects to the filter maintenance gallery at the north end. The filter maintenance gallery is located at grade and a hoist or platform lift will be provided for maintenance access to the filter pipe gallery to remove equipment. Roll-up doors will be provided at either end of the filter maintenance gallery. The gallery houses the air scour blowers, backwash supply control valve and flow meter, backwash supply vent to prevent overpressurization of the filter underdrains, and the filter-to-waste air gap assembly. The current layout assumes filter-to-waste is conveyed through the backwash header to an air gap arrangement which allows discharge into the waste backwash piping in the filter maintenance gallery. Subsequent design stages will evaluate the feasibility of this approach versus a conventional approach with dedicated filter-to-waste piping.

Overflow weirs/chambers are provided for each process basin upstream of the rapid mixing chambers and above the intermediate gallery between the sedimentation and ozone contacting basins. In the event of an overflow event due to closed downstream gates or valves or some other major hydraulic constraint, the operating water surface in the treatment basins will rise and overflow into one or more of the overflow chambers and flow by gravity through the drain pipe header to the equalization basin. Large volume overflows can also overflow the EQ basin to the dewatering beds at the north end of the plant site.

Upper Level Description

The upper level of the advanced treatment module will be located approximately 5 - 20 feet above grade elevation. Concrete walkways will be provided around all pretreatment unit processes to allow for access to mixer motors and viewing and/or periodic cleaning of the plate settler units in the sedimentation basins. The upper level over the rapid mix, flocculation, and sedimentation basins will be one common space. North of the sedimentation basins is the ozone generation room which houses ozone generators and power supply units (PSUs), open loop and closed loop cooling water pumps, ozone off-gas destruct units (ODUs) and associated oxygen and ozone gas piping and flow control valves. North of the ozone generation room is the filter operating gallery. An operating room is located between the two banks of filters. An electrical room and mechanical room are located at the north end of the facility. A glass-walled water quality laboratory and operators control room is shown in the center of the filter operating gallery. This location will allow plant personnel to operate the plant with convenient access to filters and ozone equipment room for routine operation and maintenance activities.

Appendix A - Pre-design Investigations for Process Train Selection

Table A-1 Summary of Pre-Design Investigations Impacting Process Train Selection

Item	Topic	Key Investigations and Findings	Implications for Process Train Selection
Technical Memorandum No. 1: Regulations, Source Water Quality and Finished Water Quality Goals (October 2019)			
1	Regulatory Overview	▪ Summary of USEPA primary and secondary drinking water quality standards (TM 1 Appendix A) ▪ Summary of potential future regulated water quality (WQ) parameters and contaminants of emerging concern (TM 1 Appendix B)	▪ Process train must meet current drinking water quality standards for all source WQ conditions ▪ Consider advanced treatment processes (ozone, GAC, UV) to meet Cryptosporidium and CEC regulations now or in future
2	Source Water Quality Assessment	▪ Defined Normal, Challenging and Catastrophic WQ conditions, including frequency of occurrence (TM 1 Section 3.1) ▪ Characterized post-wildfire WQ conditions in Clear Creek watershed (TM 1 Table 3-5) ▪ Source WQ for normal, challenging, and catastrophic conditions were benchmarked (TM 1 Table 3-6)	▪ Process train must meet Level 1 (utility-based) WQ goals for normal and challenging source WQ conditions ▪ Process train must meet Level 2 (regulatory-based) WQ goals for catastrophic conditions (i.e., post-wildfire and other extreme watershed events) ▪ Consider advanced treatment (ozone, GAC) for challenging and catastrophic source WQ conditions
3	Finished Water Quality Goals	▪ Level 1 (utility-based) and Level 2 (regulatory-based) WQ goals established for five categories (microbial, disinfection by-products (DBPs), organics/inorganics, secondary standards, and CECs (TM 1 Section 4) ▪ Microbial WQ goals achieved through multi-barrier disinfection strategy (TM 1 Table 4-1) ▪ WQ goals for DBPs and inorganics set 25-30% lower than regulatory MCLs (TM 1 Tables 4-2 and 4-3) ▪ WQ goals for turbidity, manganese and corrosion control set based on full-scale performance at Semper WTP (TM 1 Table 4-4) ▪ T&O removal goals set below typical odor thresholds for MIB and Geosmin metabolites to avoid customer complaints (TM 1 Table 4-4)	▪ Use multi-barrier disinfection strategy (filtration, chlorine, ozone) to meet microbial WQ goals ▪ Use sodium permanganate as preoxidant to meet Mn goal based on Semper WTP experience ▪ Use chloramines as secondary disinfectant to meet distribution system WQ and DBP goals ▪ Use pH /alkalinity adjustment with lime and caustic soda chemicals to meet corrosion control goals ▪ Consider ozone-biofiltration process to meet T&O, filterability and biostability goals for challenging and catastrophic source WQ conditions ▪ Consider future UV disinfection upgrades for regulatory compliance if Cryptosporidium occurrence levels increase in Standley Lake

Item	Topic	Key Investigations and Findings	Implications for Process Train Selection
4	Treatment Performance Goals	▪ Low SW and FW turbidity "stretch" goals established for normal WQ conditions (TM 1 Table 4-6) ▪ Uniform filter run volumes (UVRVs) should exceed 8,000 gal/ft^2 (TM 1 Table 4-6) for efficient filtration ▪ Consider biofiltration EBCT of 5 min at design flow to enhance biodegradable organic carbon removal (TM 1 Table 4-6)	▪ Select type and depth of filter media, and filter loading rate to meet turbidity, UFRV and EBCT treatment performance goals based on pilot plant results
Desk-Top Study Report (DTR): Pilot Plant Process Selection and Water Purification Facility Concept Design (June 2020)			
5	Treatment Process Screening	▪ Candidate treatment technologies for piloting included: pre-oxidation, clarification and filtration treatment processes (DTR Section 2) ▪ Conventional and ozone-biofiltration process trains plus 8 treatment chemicals were selected for piloting (DTR Figure 2-6)	▪ Only consider treatment technologies and chemicals selected for pilot study for process train selection
6	Process Design Criteria and Concept Layouts	▪ Preliminary design criteria for unit processes established for both conventional and ozone-biofiltration process trains (DTR Section 3) ▪ Conceptual layouts developed for individual unit processes to determine how they fit together as a consolidated treatment train module (DTR Section 3)	▪ Use preliminary design criteria and facility layouts to evaluate conventional vs. ozone-biofiltration process trains, treatment module configuration and dimensions, and construction cost estimates ▪ Update filtration design criteria based on pilot study results
7	WTP Site Assessment	▪ Basic layout and overall dimensions established for standard treatment process modules for conventional and ozone-biofiltration process train alternatives (DTR Figure 4-2) ▪ Facility footprint site assessment confirmed that the 30-acre site for the new WTP is sufficient for construction of Phase 1 and Phase 2 treatment facilities	▪ Use standard treatment process module layout for both conventional and ozone-biofiltration design alternatives ▪ Construct one 30-mgd treatment module with two 15-mgd process trains for Phase 1 WTP capacity of 30 mgd ▪ Construct two 30-mgd modules for Phase 2 WTP capacity of 60 mgd ▪ Reserve space on plant site for constructing one 30-mgd treatment module prior to replace Phase 1 module for Phase 3 WTP capacity of 60 mgd

Item	Topic	Key Investigations and Findings	Implications for Process Train Selection
Desk-Top Study Report: Appendix D, Technical Memorandum No. 3 - Water Treatment Bench-Scale Test Results (December 2020)			
8	Coagulant Test Results	▪ Ferric chloride and ACH outperformed alum for turbidity and TOC removal at optimal dose of 6 to 7 mg/L ▪ Equivalent ferric chloride performance was achieved at pH 7.5 and 8.1	▪ Select ferric chloride as primary coagulant ▪ Provide ferric chloride application points before and after pH adjustment by lime addition for low- and high-pH coagulation treatment flexibility
9	Preoxidant Test Results	▪ Ozone, chlorine dioxide and permanganate pre-oxidants did not change optimal ferric chloride dose ▪ Ozone demand for settled water was lower than for raw water with lower ozone residual decay rates	▪ Use sodium permanganate as preoxidant based on Semper WTP experience for Mn removal ▪ Consider intermediate ozone for disinfection and T&O reduction at low ozone doses (< 1 mg/L)
Pilot Plant Test Report (January 2021)			
10	Coagulation Test Results	▪ Piloting confirmed optimal ferric chloride dose of 7 mg/L for turbidity and TOC removal ▪ Challenge test results indicate higher ferric chloride dose (up to 30 mg/L) required for turbidity and TOC removal	▪ Establish ferric chloride design doses based on bench-scale and pilot plant results for normal and catastrophic WQ conditions
11	Filtration Test Results	▪ Anthracite media was slightly more effective than GAC for turbidity reduction but both types met turbidity goal (< 0.1 NTU) ▪ Filter UFRVs averaged 15,000 to 20,000 gal/ft^2, significantly exceeding filtration performance goal by 2X or more ▪ Filter loading rates of 10 gpm/ft^2 met turbidity goal and reduced TOC by 5-10% through the filters ▪ Challenge tests resulted showed no negative impacts on filter performance, due to effective coagulation and settling ▪ Coarse media depth of 48 inches provided effective treatment and acceptable operation	▪ Select GAC or anthracite filter media for filter design based on benefit/cost tradeoffs ▪ Design filters based on 10 gpm/ft^2 with two filters out of service for backwash and maintenance and 8 gpm/ft^2 with one filter out of service for backwash only ▪ Select filter depth between 48 and 72 inches of coarse media based on benefit/cost tradeoffs
12	Ozone-Biofiltration Test Results	▪ Ozone-biofiltration process at low ozone dose (< 1 mg/L) improved turbidity, TOC, and AOC reduction compared to non-ozonated filter columns ▪ Ozone effectively removed odors during source water challenge testing compared to non-ozonated filter columns	▪ Select ozone-biofiltration process train for implementation if project budget constraints are met